OVERVIEW OF METHODS AND INSTRUMENTS FOR MEASURING THE EXTERNAL AND INTERNAL DIMENSIONS OF CLIMATE FROM C.1800

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ABSTRACT

This paper provides an account and analysis of the methods and instruments used for measuring climate in architecture focusing on the late modern period from c. 1800 to the present. The methods were classified after identifying two major trends according to their ultimate objective: measuring the external dimension of climate (meteorological statistics and facts about temperature, humidity, wind, sun radiation, or/and pollution) and measuring the internal dimension of climate (Healthcare outcomes and climate narratives). This report provides key examples, and evidence of their impact over human experience. Revealing a neglected inner dimension that needs a cultural approach to be measured.

Climate is experienced on a local and particular level as individuals feel, embody, and are engaged with the rhythms of their environment in a visceral and emotional way that statistics alone cannot register. As climate is not only the temperature of the air, and as climate is chained to land, vegetation, animals, and life, new hybrid methods for measuring simultaneously its inner and external dimensions are needed. New methods that can collect, and interpret climatic data tandem to human well-being and their sensorial environments.

Keywords: architecture, climate, instruments, external dimension, internal dimension, measurement.

REVISIÓN DE MÉTODOS E INSTRUMENTOS PARA MEDIR LAS DIMENSIONES EXTERNAS E INTERNAS DEL CLIMA A PARTIR DE C.1800

RESUMEN

Este documento proporciona una revisión y un análisis de los métodos e instrumentos utilizados para medir el clima en la arquitectura centrándose en el último período moderno cerca de 1800 hasta el presente. Los métodos se clasificaron después de identificar dos tendencias principales de acuerdo con su objetivo final: medir la dimensión externa del clima (estadísticas meteorológicas y

datos sobre temperatura, humedad, viento, radiación solar y/o contaminación) y medir la dimensión interna del clima (Resultados médicos y narrativas climáticas). Este informe proporciona ejemplos clave y evidencia de su impacto sobre la experiencia humana. Revelando una dimensión interna descuidada que necesita un enfoque cultural para poder ser medido.

El clima se experimenta a nivel local y particular a medida que los individuos sienten, encarnan y se involucran con los ritmos de su entorno de una manera visceral y emocional que las estadísticas por sí solas no pueden registrar. Como el clima no es solo la temperatura del aire, y como el clima está conectado a la tierra, la vegetación, los animales y la vida, se necesitan nuevos métodos híbridos para medir simultáneamente sus dimensiones internas y externas. Nuevos métodos que pueden recopilar e interpretar datos climáticos junto al bienestar humano y sus entornos sensoriales.

Palabras claves: arquitectura, clima, instrumentos, dimensión externa, dimensión interna, medición.

1. INTRODUCTION

This overview was originated from the preparation for the Comprehensive Exams in the PhD Program in Latin American Studies (Concentrations Built Environment and Geography & Environmental Studies) of the University of New Mexico UNM in the semester Fall 2016.

This report provides an account and analysis of the methods and instruments used for measuring climate in architecture focusing on the late modern period from c. 1800 to the present, within a larger research inquiry about the evolution that the concept of climate have had for modern architects. The methods and their instruments were classified after identifying two major subjects of measurement: measuring the external dimension of climate and measuring the inner dimension of climate. This report provides key examples, and evidence of their impact over human experience.

The review of the literature revealed that although there is abundant architectural research regarding the history and design of sustainable buildings, historical research on the theoretical foundations of the modern scientific preoccupation with climate and its logic of method, measurements, and instruments is limited. The following overview contributes to the field of Architecture from an exceptional historical-geographical standpoint.

Therefore, the purpose of this paper within research about the modern idea of climate in architecture is to contribute to a new comprehension of the history of climate in architecture. Bridging the larger fields of Architecture and Geography and challenging some of the most naturalized concepts and methods of sustainable architecture, while simultaneously contributing towards more holistic scientific approaches to design-with-climate that consider hard data alongside arts and poetics.

In addition, this paper is the result of an interesting interdisciplinary effort between the departments of Architecture and Planning and Geography & Environmental Studies of UNM through the author of this paper and her dissertation committee.

This paper is composed by five sections. Section I is the current introduction and foreword. Section II explains the methods used to select the literatures, themes, and bibliography to review and the method of analysis. Section III is the body of the paper with a brief framework to understand the concepts of measurement and climate related to the built environment. This section is divided in two sub-sections: Sub-Section a presents the methods and tools used for measuring the external dimension of climate through an institutionalized measurement of climate and Urban Climatology (meteorological statistics and facts about temperature, humidity, wind, sun radiation, and pollution). And Sub-Section b presents the methods and tools for measuring the inner dimension of climate through Healthcare outcomes and climate narratives. Section IV presents relevant conclusions. A complete list of References is included.

2. METHODS

The author of this report was required to consult bibliographical sources as widely as possible in three scholarly literatures. These literatures were relevant to her dissertation focused on the history of architecture's development in tandem with theories of climate/environment, aiming to understand the evolution of the modern idea of climate in architecture.

Three literatures were selected for their focus on the production of knowledge about climate and the built environment: 1. Historical Geographies of Science, 2. Theory and History of Architecture, and 3. Sustainable Architecture.

The themes and topics considered to select the final bibliography to be reviewed were:

- Foundational works in Historical Geography and Science and Technology Studies STS
- Histories of Geography and Histories of Science.
- Histories of environment and climate knowledge.
- Climate change: Knowledge and Discourse.
- Climate and the Urban/Built Environment.
- Climate and Atmosphere.
- Bioclimatic architecture and thermal delight.

The bibliography's primary sources were original works by seminal authors, and its secondary sources were contemporary works by relevant scholars. The Historical Critical Analysis and Interpretation of the bibliography produced at first the following thesis and question: if architecture is the bridge and mediator between climate and people, then which are the qualities that make these buildings and settings effective in bridging climate and the human experience? Developing therefore, a second thesis and question: in order to understand those qualities in buildings, first there is the need to identify and evaluate the methods and tools that have been used for measuring climate and how these tools have impacted human

experience? Finally, the Critical Historical Analysis of the bibliography concentrated the answer between the late modern period from c. 1800 to the present. This paper presents the answer only to the second question. The answer to the first question will be presented in a following publication.

3. MEASUREMENT, CLIMATE, AND THE BUILT ENVIRONMENT

Measuring, a task which is performed almost daily, is one of those core concepts not easy to define; however, the act of measuring is performed to know the dimension of something, involving amount, size, length, depth, limits, boundaries, degree, shape, or form. One can see something, or knowledge can be acquired by measuring.

Another concept with many meanings is climate, which after 1800 became slowly accepted as the total experience of weather conditions over some specific period of time (30 years) (Lamb, 1982), and weather as the state of those conditions in the atmosphere at one point in time and place (Fleming, 2010, p. 6).

Meteorology became the science of atmosphere and weather prediction, while general climatology became the study of the processes of climate as a system that involves the atmosphere, land, oceans, and living beings; meteorology and climatology are sciences rooted on the measurement of weather conditions.

Regarding methods and tools for measuring that complex climate, the period between 1800 and 2016 can be roughly divided in two major types: on one hand, the most common and known of meteorological statistics and facts which allowed to measure and analyze the external dimension of climate. But, on the other hand, contemporary scientists, scholars, and amateurs from many backgrounds are increasingly studying climate as a hybrid phenomenon (Endfield & Morris, 2012) that besides its quantifiable external dimension, has an inner dimension that occurs within the “imagination” (Gorman-Murray & Waitt, 2009) of the humans who feel it. Meaning that climate can be studied from the ‘interior’ through the study of sensorial experience, mental assimilation, social learning, and cultural interpretations. This paper will discuss and evaluate those two larger dimensions of climate measurement relating them to the built environment.

a Measuring the external dimension of climate: Institutionalized climate measurement and Urban Climatology (meteorological statistics and facts about temperature, humidity, wind, sun radiation, and pollution)

The thousand moods of the sky and the secrets of air had interested people since long ago, from Ptolemy of Alexandria who kept a weather diary around AD 120 (Lamb, 1982, p. 159); to the appearance of instruments to measure numerically weather conditions in the First Scientific Revolution like the barometer (humidity) and the thermometer (temperature); up to the amateur meteorology culture that appeared in Europe around 1750 keeping laborious weather journals, calendars, or chronicles to register extraordinary or freak climatic occurrences in their local places (Endfield & Morris, 2012). But, it was the Second Scientific Revolution around 1800 which united all of those individual, assorted, and informal weather measurements under a system grounded on the standardization of units, methods, tools and techniques that the new science of measurement, Metrology, made possible (Naylor, Nationalizing provincial weather: Meteorology in nineteenth-century , 2006; Heymann, 2010). The construction of a physical network

of new weather observatories and stations (to measure temperature, humidity, rain, sun hours, cloudiness, and atmospheric pressure) was disseminated along territories institutionalizing the sciences of meteorology and climatology.

Metrology, the construction of common standards of measurement, began with the definition of *the meter*, a gigantic enterprise of 6 years that took place in the middle of the French Revolution. The quest to define a unit of measurement suitable 'for all people in all ages,' happened under the peak of a revolution whose ideals were: "equality, universality, objectivity, and permanence illuminated by the light of Reason. In 1791, the quarter section of the earth's meridian was adopted as the universal standard of measurement, the earth itself was chosen as the standard […] the earth, shared by all men, invariable, universal" (Guedj & Goldhammer, 2001, p. 294). The entire system was created upon the new unit of measure: one-ten-millionth of the quarter meridian, called meter, from the Greek *metron* which means measure (Merriam-Webster, 2015). A standard new unit for a new world, literally and metaphorically.

Meteorology and climatology appeared under this gigantic system, and the idea of a national weather helped the construction of national identities (Naylor, Nationalizing provincial weather: Meteorology in nineteenth-century , 2006)**;** partly explaining why the measurement of the external dimension of climate hasn't really changed in 200 years. Today, the idea of a national climate is being replaced by the idea of a global climate.

This dominant method to measure climate is a system that uses a network of local stations to measure weather conditions, to later submit those data to centralized offices in metropolises where they are processed and interpreted in the form of annuals and charts to be used by networks of professionalized sciences, or communication networks to reach the public.

The measurement of the external dimension of climate impacted human experience since its beginning by allowing the creation of a communal sense, used to foster the feeling of belonging to a nation. A process that today is uniting people under the umbrella of a global changing climate; however, this global public perception overshadowed to some extent the local understandings of climate. That is why many scholars are seeing a struggle between a planetary sense of belonging with a local sense of place (Jasanoff & Martello, 2004; Morin & Kern, 1999). Bruno Latour reflected about the impact of Metrology: "…which makes of the outside a world inside which facts and machines can survive. Termites build their obscure galleries with a mixture of mud and their own droppings; scientists build their enlightened networks by giving the outside the same paper form as that of their instruments inside. In both cases the result is the same: they can travel very far without leaving home." (Golinski, 1998, p. 173)

This signifies that Metrology allowed a remote control of space and people due to the institutionalized and professionalized methods and tools for measuring, and in the specific case of climate, allowed a severe impact over human experience (of course this seen from the perspective of the XXI Century) as it was used to justify climatic determinism, imperialistic expansions, spread of international standardized architecture, and the slow fading of certain vernacular knowledge, life styles and architectural languages.

Nonetheless, among this large constant method and network to measure weather conditions, the tools have been improved greatly, along with new practical uses and disciplines, like urban climatology and micro-meteorology born to improve

human experience in the industrial larger city. If climatology studies the processes of the general climate (above the skyline), then, urban climatology studies the processes of the 'man-made climate' of the city (under the skyline). That complex technological achievement which is the city (Kwinter, 2007), changes the local air and atmosphere due to its social, animal, vegetal, morphological, energetic, or functional layers. Meteorology is to climatology what micro-meteorology is to urban climatology. As early as the XVII Century there are records of the perception that large cities changed their climates: "cities insufferable in summer […] heat created by a large city […] the temperature of the city is not to be considered as that of the surrounding climate […] it is impossible that this turbid, smoky, ammoniacal atmosphere should not have a notably higher temperature than the surrounding country, the urban anomaly." (Janković, 2013)

Then, with the growth of urban weather stations since the 1800's two mayor things occurred: first, the city climate was officially measured and studied (documenting the spatial distribution of atmospheric parameters in urban landscapes); and second, the public health movement appeared to study the connection between bad airs or miasmas with physical and mental health.

Measurement of urban climate impacted human experience by promoting a new urban design based on air flow, ventilation and hygiene. Urban weather stations provided evidence to achieve political changes like recognizing pure air as a necessity, transformed into policy as atmospheric rights. By 1900 there was a theory of Urban Heat Island, and micro-meteorology was studying the urban climate at smaller scales and higher vertical layers (interaction among housing, industrial, and commercial districts, water, topography, and vegetation) by measuring: sun, wind, rain, temperature, and pollution in the air. All these efforts were condensed in Meteorological Principles of Town Planning. Several architects and urban planners like Charles Édouard Jeanneret better known as Le Corbusier or Ludwig Hilberseimer (Janković, 2013), along with geographers and climatologists applied those principles of natural climatic planning on many European cities. Furthermore, the measurement of city climate was helping to understand the dependence between life and climate, and by 1934 the first graduate seminar in Bioclimatology was held across the ocean in the United States (Janković, 2013), while a new current of micro-meteorologists with home-made instruments appeared.

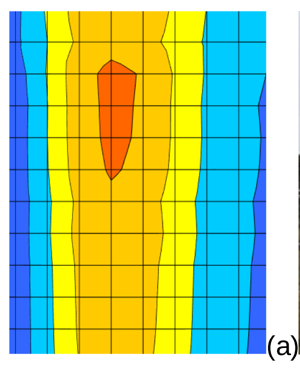
After 1950, the instruments were still measuring the same parameters but thanks to sensors, automatic recorders, and balloons, they were reaching higher places allowing research in: control of city climate through design, measurement of urban heat island with isomaps and isotherms as showed in Figure 1 (a), air pollution, military weapons (Fleming, 2010), and bioclimatic architecture under Victor and Aladar Olgyay (Olgyay & Olgyay, 1963). In this decade, computers begin to transform all that climatic documentation into numerical climate modeling (Barber, May 15, 2014), analysis, and prediction (Dutta, 2013) which by the 1970's focused on understanding climate as a physical system under change, and by the new millennium, it was clear that humans affected climate through their cities and life styles.

Today, the method to measure the external dimension of climate is basically the same as the one started in 1800, but the tools and instruments keep becoming smaller, cheaper, and more precise; the process and interpretation of

data is largely computerized, and its network globalized. Figure 1 (b) displays a generic weather station in Ecuador.

When urban climatology started, it provided evidence for political changes and design decisions to improve health in cities; 200 years later, it still is doing the same in larger metropolis that still suffer ventilation crisis, overuse of air conditioning, and stresses health (Hebbert, 2011). Architects, urban climatologist, micro-meteorologists, and new amateurs, are providing new information of urban climate using portable weather stations connected to smartphones which can forecast and measure weather: temperature, humidity, barometric pressure, sun radiation, shrinking sky-views, blueness of the sky, and CO2 levels as showed in Figures 1 (d) (e) (f) and (g).

Perhaps the most interesting potential of these smaller stations is threefold: first, their capacity to demonstrate to architects and dwellers that climate is actually a material to design despite being *invisible*; second, these portable stations have a capacity to measure climate not only of the outdoor city climate but of the indoor; recognizing the importance to understand the external dimension of climate at the most inner intimate dimension of the city: inside the 'homes.' And third, the climatic localized peculiarities of each city are being recognized, challenging traditional regional climatic maps.


(a)


(b)



LEED® Facts

Sidwell Friends Middle School
Washington, D.C.

LEED for New Construction
Certification awarded March 14, 2007

Platinum	57*
Sustainable Sites	11/14
Water Efficiency	5/5
Energy & Atmosphere	13/17
Materials & Resources	8/13
Indoor Environmental Quality	15/15
Innovation & Design	5/5

*Out of a possible 69 points

(c)

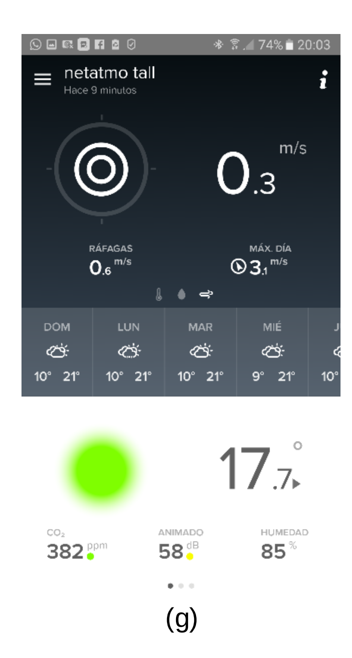


(d)



(e)


(f)



(g)

Figure. 1 Measurements of the external dimension of climate: (a) Isotherm chart (year and hours) made with meteorological data gathered by meteorological station #2 'La Morita' in Quito, Ecuador (Evans & Delbene, 2004); (b) Meteorological station in Ecuador' (http://www.conocimiento.gob.ec/, n.d.); (c) Measurement of the external dimension of climate through atmosphere and indoor air quality in LEED Tag of certified building (U.S. Green Building Council, 2007); (d) NETAMO Personal Urban Weather Station connected to smartphone (NETATMO, 2011); (e) NETAMO Personal Urban Weather Station (Freire U. A., 2017); (f) NETAMO Personal Urban Weather Station's additional wind gauge (Freire U. A., 2017); (g) Smart Phone screen capture of NETAMO Personal Urban Weather Station's displaying external dimension of climate (Freire U. A., 2017).

b Measuring the inner dimension of climate: Healthcare outcomes and climate narratives

The period between 1800 and 2016 was characterized by a collective effort to measure the external dimension of climate, neglecting the study of its inner cultural dimension, yet never forgetting it completely. For example, even at the very beginning of metrology and its use of national climate measurements to construct national identity, to the links of city climate to health, there were records of the complex and subjective effects of climate over people.

That *inner dimension* of climate is difficult to tabulate and harder to measure because it occurs in the "imagination" of those who feel it through sensorial experience, mental assimilation, social learning, and cultural interpretations. Climate can only be comprehended when its physical dimensions are allowed to be interpreted by their cultural meanings (Gorman-Murray & Waitt, 2009), so, the XXI Century is seeing a movement that is increasingly curious about how climate is registered in memory, behavior, text or/and identity just as it is measured through meteorology.

One attempt to measure the physiological and psychological effects of climate was the definition of a thermal comfort zone in the 1960's (Olgyay & Olgyay, 1963) as showed in Figure 2 (d); scientific experiments involving animals and people tried to determine a standard comfort, an ideal temperature and humidity at which everyone would feel comfortable. During the American context of energy crisis of that time (Dutta, 2013, p. 260), this comfort was understood as a constant thermal environment in which a person could function efficiently without the effort and distraction of a constant need to adapt to different environmental conditions (Knechtel, 2010, p. 214). Different comfort zones appeared according to different countries: 'British', 'American', or 'Tropical' (Olgyay & Olgyay, 1963, p. 17), ignoring particularities, for instance: a desert dweller from New Mexico would have the same comfort zone as someone from Alaska? And what was regarded as tropical people still had a pervasive influence of climatic determinism (Greer, 2015).

This comfort spread from the United States along the world, but by 1980's was questioned by the human need for contrast. Lisa Heschong (Heschong, 1979) represents a movement which rediscovered through vernacular architectural and cultural studies that people find changing climates pleasurable. By 2016, interdisciplinary studies are recognizing how mind and body need constant adaptation, which is subjective. Interestingly, every person is capable of feeling delight through the complete stimulation of the senses, and there are aspects that can sparkle delight in most, but the intensity in which is felt and registered cannot be standardized.

The comfort zone measured if the climate of a place was within the standard, if it wasn't, the designer should implement design solutions, and within the context of the time, modern technical and engineering climatic solutions ignored the sensorial heritage of people. By the year 2016, is recognized how that technological paradigm of design and development became *unsustainable*. Certification and rating systems for green buildings like LEED, are rising, and while very worthy and necessary, they still only measure the external dimension of climate; the sensorial reaction, memory, social behavior, or cultural meaning of the inner dimension still is not measured as showed in Figure 1 (c).

The new architecture recognizes that climate and comfort contain both sensuous and measurable properties (Dahl, 2010, p. 142), then, the sensuous is an unmeasurable property? Not quite, there are interesting attempts to measure the sensuous indirectly, through the measurement of: Household Sustainability (the domestic: the insignificant every day practices show the intimate links between dwelling and climate); Poverty (how low income people solve their design and life style - people are part of the solution versus top down 'solutions'); Urban Revitalization (measuring attendance to 'lively' places) (Gorman-Murray & Waitt, 2009). There even are historical studies that are finding surprising parallels between the climatic and cultural curves of transition; social upheavals coincided with climatic changes, one caused the other and vice-versa (Lamb, 1982, p. 318).

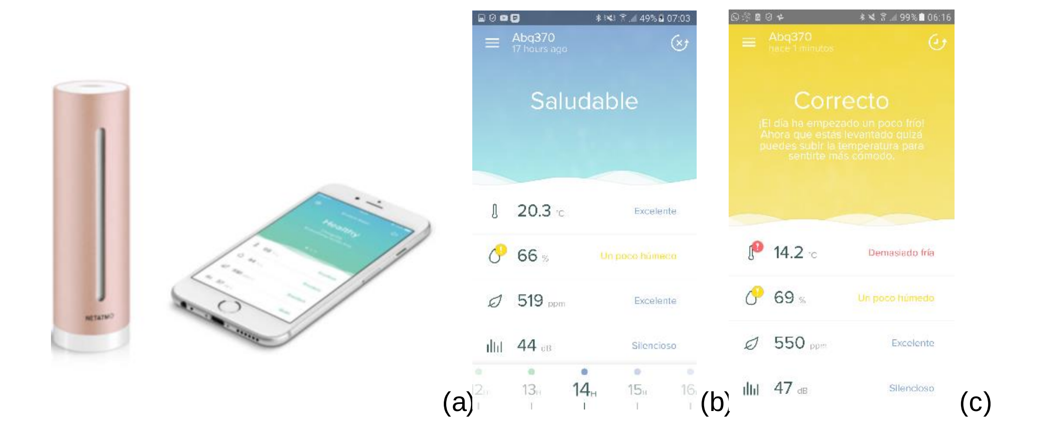
But today, probably the most advanced field in the attempt to measure the inner dimension of climate is HealthCare (like the Public Health movement in 1800's). Built environments still suffer bad air, industrial chemicals, and lack of sun, but there is a new major healthcare concern today: critical stress. That is why healthcare offers an opportunity to measure the inner dimension, by measuring objective parameters of stress reduction in patients (suffering extra stress due to illness and hospitalization). By measuring at the same time patients and the actual

hospital building environments, the invisible benefits of a sensorial stimulating climate becomes visible.

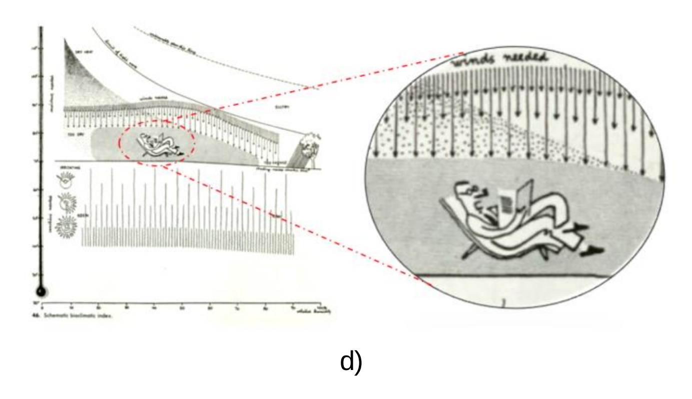
These healthcare quality measurements are called Health Outcomes and include: 'observable symptoms in patients (consumption of pain medication, blood pressure, and days in hospital); satisfaction (patient or staff satisfaction, health related quality of life); safety (infection rate, falls); economy (cost of patient care, revenue from patients choosing a facility)' (Kellert, Heerwagen, & Mador, 2008, pp. 88, 89). The correlation of health outcomes with building climatic measurements have shown how a sensual nature, climate, land, vegetation, and animals introduced to the built environment fosters repair from stress.

Outside academia, there are interesting artistic attempts of measurement called climate narratives, where paintings or literature are being revisited to analyze how climate has been recorded; or multimedia initiatives like Memoryscapes: 'audio walks about people entwined with their environment and climate along a city's natural feature like a river or forest (Driver, 2013; Livingston, n.d.).

Finally, there are applications for smartphones or tablets called Ambiance Sensors (McKenzie, 2016) (currently under development) or Smart Climate Monitors connected to personal weather and air care stations (NETATMO, 2011) that register the performance of buildings by measuring the preferences of users about their places through smartphones that measure the external weather parameters as shown in Figures 1(d), (e), (f), (g) and 2 (a), (b) and (c). Probably this effort of crowdsourcing and correlating the external and internal dimensions of climate will provide evidence based on people's selection and use of places due to the positive impact over their senses and health. Despite one might ask what about privacy? Ambiance Sensor Apps are being developed to be sold to large companies, universities, hospitals, or airports in order to measure user's climatic preferences, and attract more clients or foster productivity in employees. In addition, smart phones with personal weather and air quality stations are allowing people to connect and be aware of the relationship between the external dimension of climate and their inner dimension.



(a) (b) (c)



d)

Figure. 2 Measurements of the internal dimension of climate: (a) NETAMO Home Coach Station connected to smartphone (NETATMO, 2011); (b) Smart Phone screen capture of NETAMO Home Coach attempting to measure the internal dimension of climate displaying a healthy environment; (c) Smart Phone screen capture of NETAMO Home Coach attempting to measure the internal dimension of climate displaying an average environment (Freire U. A., 2017); and Bio-climatic chart with man in comfort zone (Olgyay & Olgyay, 1963).

4. CONCLUSIONS

The external dimension of climate is a numerical account of the fluctuations in climate at a local scale to predict global climate and make models, ignoring how those fluctuations are felt and appropriated by individuals. Consequently, the inner dimension of climate, needs a cultural approach; climate is experienced on a local and particular level: an individual feels, embodies, and is engaged with the rhythms of his environment in a visceral and emotional way that statistics alone cannot register. How is climate felt in buildings, food, mobilization, or new traditions in the new millennium?

It seems that the inner dimension of climate needs to be measured through interdisciplinary projects that merge disciplines, technologies, and species. Climate is not only the temperature of the air; climate is chained to land, vegetation and animals.

Nevertheless, why is so important to measure that inner dimension of climate? Because evidence is needed in order to change politics that affect urban planning and architecture, improving housing, offices or schools, and transforming the conception of urban vegetation and vulnerability of the city. Evidence is needed not only to convince designers, and dwellers, but to transform those invisible climatic benefits into *tangible* economic values. As climate plays a role to solve inequalities, new hybrid methods for measuring the inner and external dimensions of climate are needed, to collect, analyze, interpret, and spread climatic data relating human well-being and their sensorial environments.

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